Project Management Challenge Conference

The Challenges Encountered and Overcome During the Development of the Space Shuttle Orbiter Boom Sensor System (OBSS)

PM Perspectives Track

March 2006

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Agenda

- Introduction and Background
- Top Level Timeline
- Project Initiation
- Early Decisions and Why They Were Made
- OBSS System Description
- Major Players
- Chronology of How Things Happened
- Technical Challenges
- Project Management Challenges
- Conclusion

Introduction

- Three fundamental variables to Project Management
  - Time – Schedule
  - Budget – Money
  - Resources – People
- Variation of any one, affects the other two

- With OBSS, the variable affected the most and that was under the least control, was the schedule

- The second biggest challenge was resources – the OBSS had team members from coast-to-coast and internationally and it was large. Many hundreds of people were involved.

- Biggest technical challenges were structural loads and damage detection size

Background

- Columbia Accident
- Columbia Accident Investigation Review Board Direction
  - *"For missions to the ISS develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the TPS, including both tile and RCC, taking advantage of the additional capabilities available when near to or docked at the ISS.*
  - *For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.*
  - *Accomplish an on-orbit TPS inspection, using appropriate assets and capabilities, early in all missions.*
  - *The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an ISS mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking."*

- Rationale for the OBSS project and the Shuttle was not going to fly again without it

Final Top Level Timeline

- <u>September 1, 2003</u> the OBSS Project begins
- <u>October 1, 2003:</u> System Requirements Review
  - First review of the OBSS System Requirements Document (SRD), NSTS 60514 that contains the functional and performance requirements for the system.
  - **NOTE:** At this time, the launch was NET September 2004.
- <u>September 1, 2004</u>: System Design Review
  - OBSS integrated level review examining the integrated design readiness of the system.
  - **NOTE:** At this time, the launch date was NET March 2005.
- <u>April 21, 2005</u>: First OPO Flight Readiness Review
  - All Shuttle elements, including the OBSS were reviewed for Flight Readiness. The OBSS still had all its certification paper open.
  - **NOTE:** At this time, the launch was date was NET than May 12, 2005.
  - Shortly after FRR, the launch date was changed to NET July 13, 2005
- <u>June 21, 2005</u>: OPO Delta FRR
  - Again, the flight readiness was examined for the July launch window. At this time, the OBSS was nearing completion of the certification paper. It was estimated that all OBSS certification work would be completed by July 9, 2005.
- <u>July 11, 2005</u>: L-2 (days) Launch Review
  - The OBSS had completed all of its activities and was certified as ready to fly on July 9, 2005. The OBSS was ready to launch on STS-114, the Space Shuttle Discovery, OV- 103.

How the Timeline Really Happened

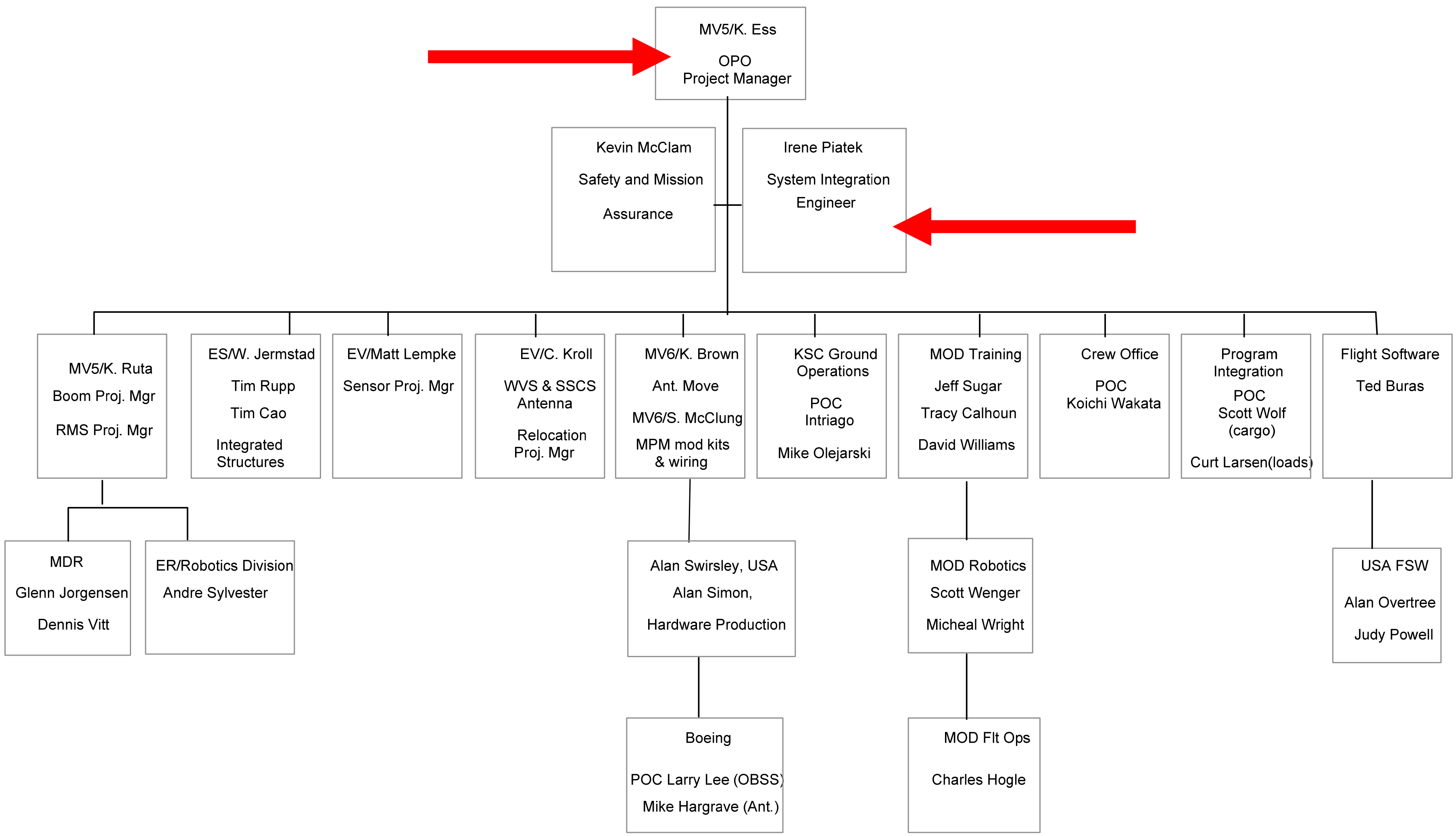
Project Milestones	**Baselined Launch Date**
September 2003 – Project Start	March 2004
October 2003 – System Requirements Review	September 2004
September 2004 – System Design Review	March 2005
April 2005 – First Flight Readiness Reviews	May 2005
May 2005 – Certification in Progress	July 2005
July 9, 2005 – OBSS Certification Complete	Actual Launch Date: July 13, 2005

Project Initiation and Organization

- **Orbiter Project Office/Engineering Directorate (EA) Agreement**
  - OPO had the official Project Manager (PM) position
    - Orbiter Prime Contractor USA and its primary Sub-contractor Boeing Aerospace were directed by personnel from the OPO
    - The Engineering Directorate provided experienced Government Furnished Equipment (GFE) project management personnel for the System Engineering and Integration (SE&I) Manager position

- **Initial Definition of Roles and Responsibilities**
  - The PM directed USA and Boeing from a contractual standpoint, report to OPO management on technical issues, budget, as well as schedule and make project-level decisions.
  - The SE&I Manager (SE&IM) provided
    - The integrated project schedule
    - Top level project requirements document
    - Integrated schematics
    - Risk management
    - Certification documentation
    - Infrastructure for design and other formal reviews and integrated issue resolution
    - The EA SE&IM provided a focal point in the Engineering Directorate for EA activities associated with the Project and report to Directorate Management for issues and status

Organization Chart



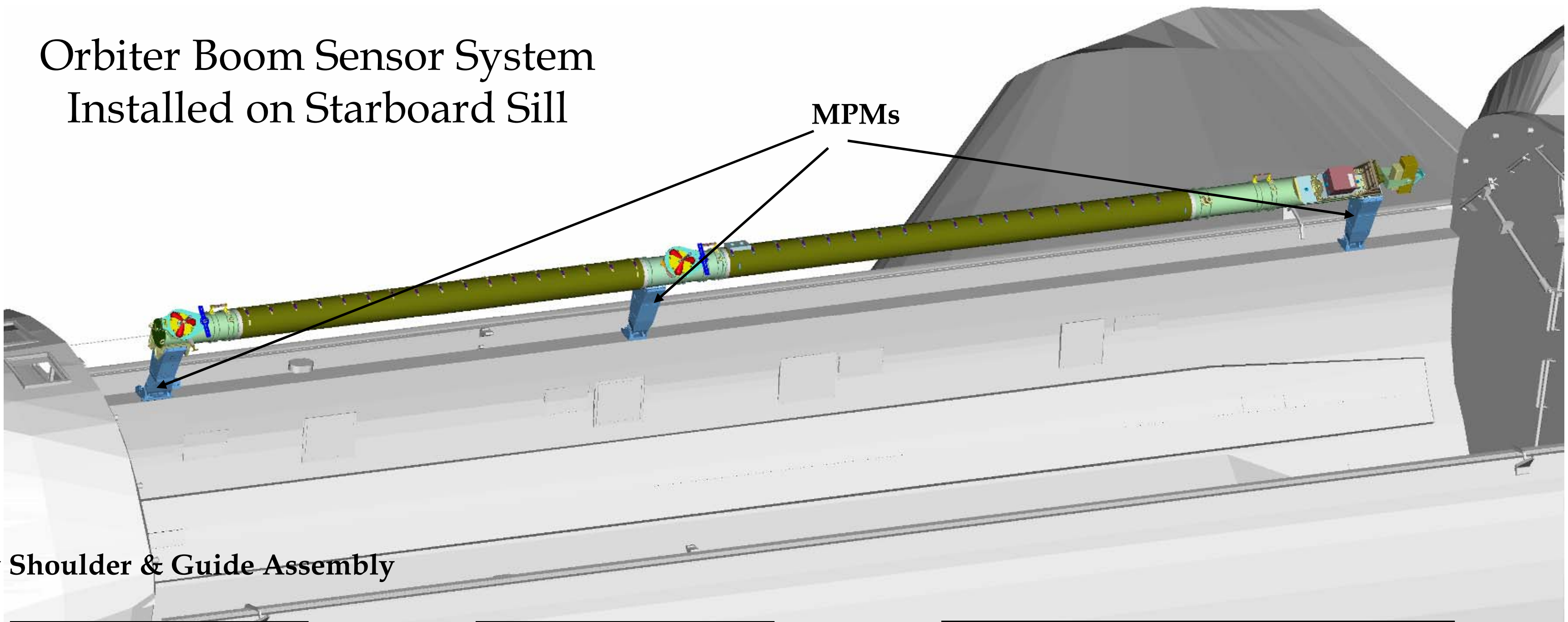
Early Decisions and Why They Were Made

- **Vehicle Infrastructure**
  - Because of the very short schedule (initially only 6 months), it was obvious to the technical community that existing vehicle infrastructure and assets would have to be utilized to the maximum extent possible.
  - The Orbiter had originally been designed to carry two robotic arms. The vehicles had a certain amount of 'scarring' or infrastructure on the starboard side of the vehicle that could be used to support a boom.
- **Boom**
  - There were two competing designs for the boom in September 2003.
    - Spare SRMS composite sections joined by aluminum transition sections.
      - The composite structure advantage was that it was existing hardware and could be designed and manufactured relatively quickly.
    - Triangular truss structure.
      - The truss was very sturdy and accommodated Extravehicular Activity (EVA) very well.
  - Both designs met the requirements known at the time. With only one year until launch, the decision was that the composite boom structure would be used for OBSS.

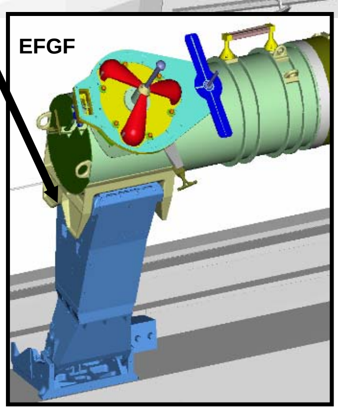
Early Decisions and Why They Were Made

- **Sensors**
  - To meet a launch date within one year, there were really only two candidates for the sensor design:
    - The Sandia National Laboratory's Laser Dynamic Range Imager (LDRI) and
    - The Neptec Laser Camera System (LCS) built by a company in Canada.
  - Both had been flown on previous shuttle missions as Development Test Objective (DTO) hardware.
    - Neither had been used during their respective DTO flights in the manner required to detect and measure small damage on RCC.
    - The DTO hardware was still available and could be used for a quick turnaround mission with what was felt to be minor modifications

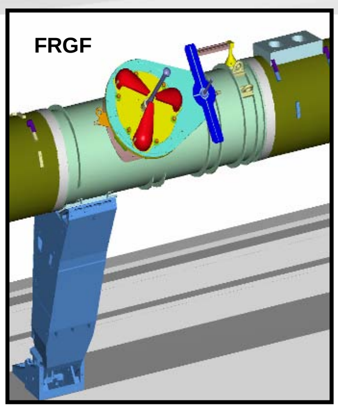
OBSS System Description



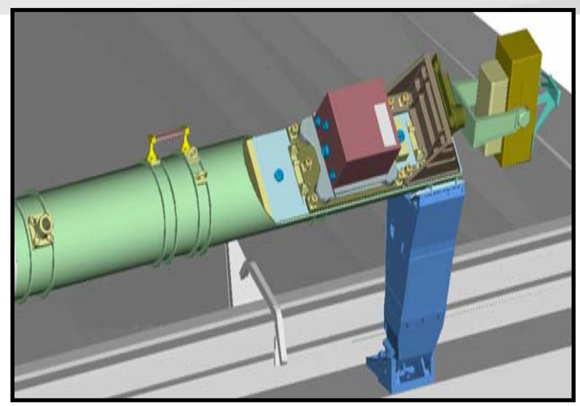
New Shoulder & Guide Assembly



Shoulder Transition



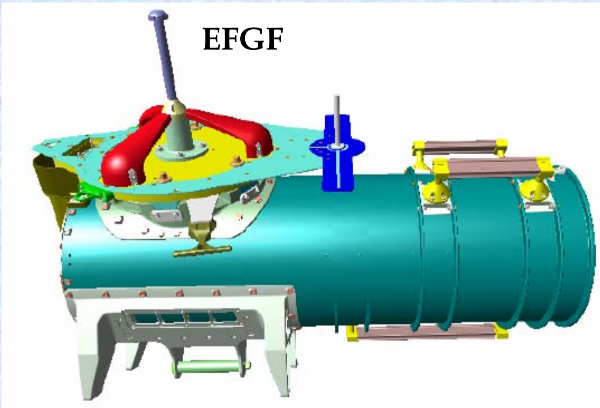
Elbow Transition



Wrist Transitions +Sensors

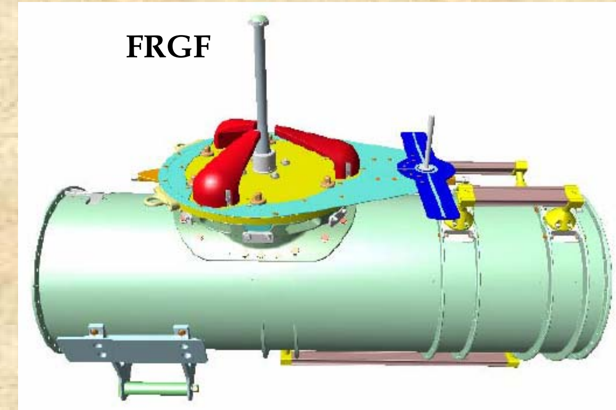
OBSS System Description

FORWARD TRANSITION ASSEMBLY



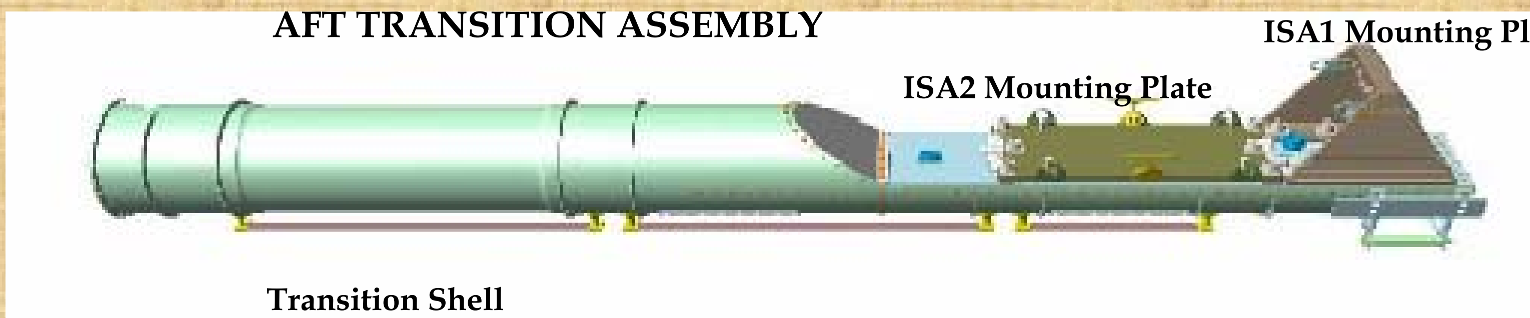
Guide Assembly

MID TRANSITION ASSEMBLY

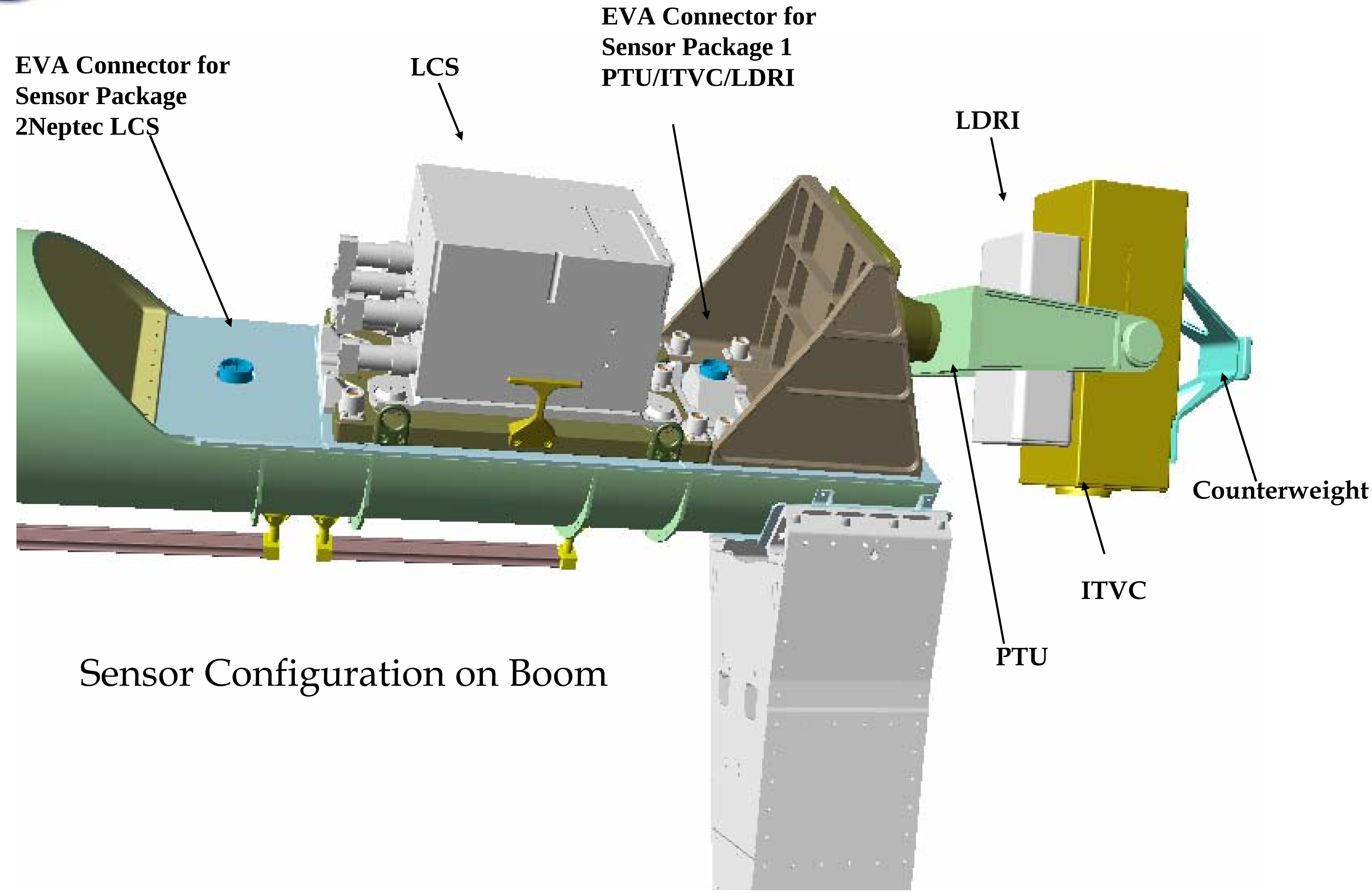


Transition Shell

MDR: Boom Transition Structures



OBSS System Description

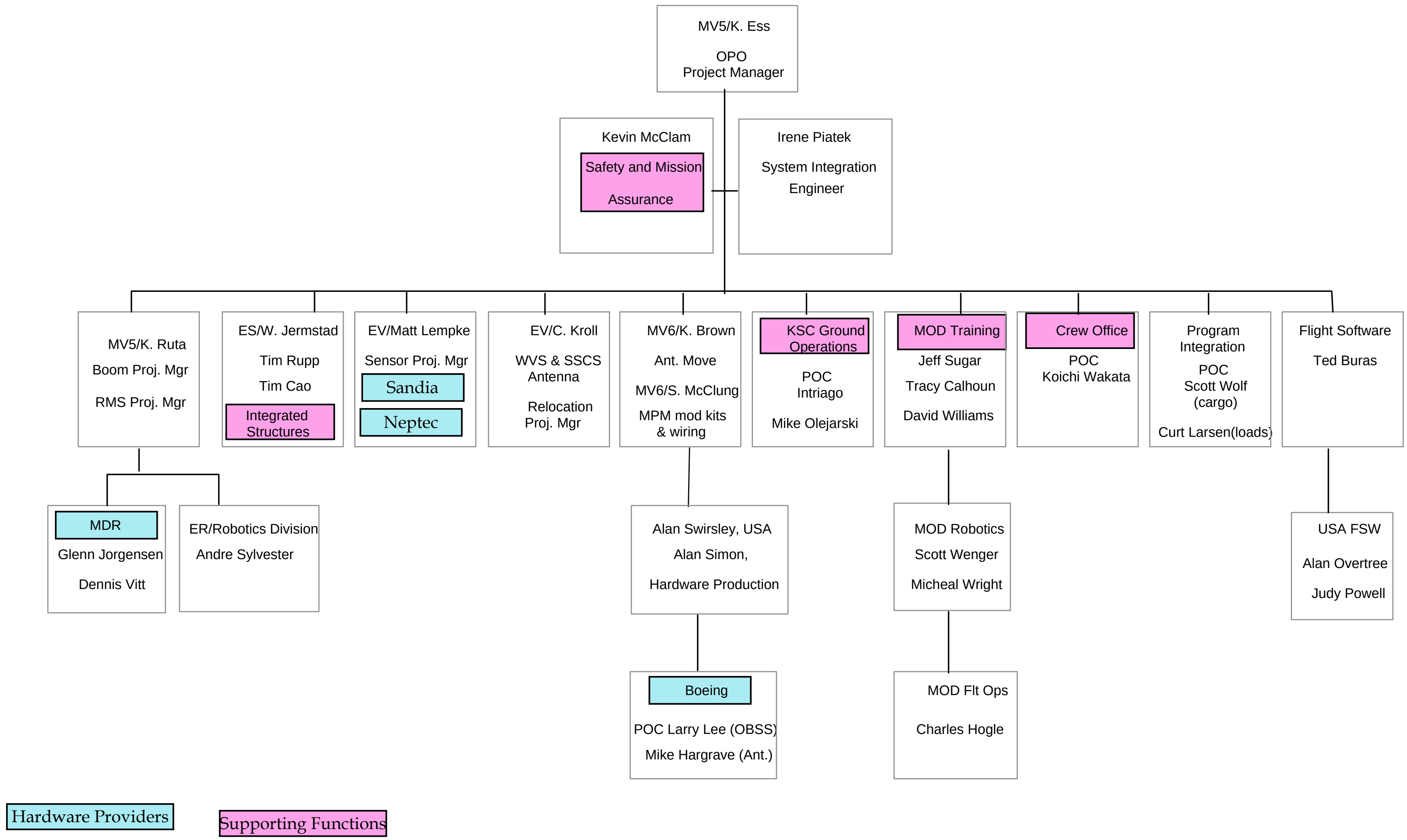


Sensor Configuration on Boom

Major Players

- Hardware Providers
  - USA/Boeing
    - Wiring pgrades, the new upper shoulder pedestal portion of the forward MPM and the saddle interface that mounts on the boom and MPMs
    - Integrated Orbiter thermal, loads and stress analyses
    - Integrated Orbiter safety analyses and hazard reports and technical installation documentation
    - the Orbiter to boom Interface Control Document (ICD)
    - Relocation of the Wireless Video System (WVS) and Space-to-Space Communications System (SSCS) Ultra-high Frequency (UHF) antennas
  - McDonnell Detwiler Associates
    - Canadian company that provides the Integrated Boom Assembly (IBA) for the OBSS
    - Provides the IBA to Sensor ICD
  - Sandia National Laboratory (SNL)
    - Provides the LDRI and its associated imagery processing software and workstation.
  - Neptec
    - Provides the LCS and its associated imagery processing software and workstation

Major Players Organization Charts



Chronology of How Things Happened

- **System Requirements Review (SRR) October 2003 – Formal Requirements Review**
  - In September 2003, the *System Requirements Document for the Orbiter Boom Sensor System, NSTS 60514*, draft was developed.
    - The SRD was needed to define the functional and performance requirements for the system. This document gave the various hardware providers a firm starting point for the development of their own requirements
    - The Systems Engineering Management Plan (SEMP) was also developed during this time.
      - Defined the roles, responsibilities, and products of each OBSS team member.
      - Established the overall Project plan, schedule, resources, reviews, risk management plan, and operations concept.
  - Since the SRD and the SEMP were fairly immature, 494 RIDs were processed.

Chronology of How Things Happened : SRR Results

- **Design Driving Requirements**
  - The OBSS has a 1R functional criticality
  - The smallest feature required to be detected and measured is 0.25” diameter through hole in the Wing Leading Edge (WLE) RCC
  - MPM with IBA berthed must survive launch and landing loads with positive structural margins
  - The MPMs shall be capable of jettisoning the IBA with installed sensors.
  - Capability to operate the OBSS without EVA involvement
  - Redundant sensors to avoid single point failure in sensor capability
  - Ability to operate the OBSS in Orbiter standalone mode and at Station
    - Station operations drive requirements for sensor positioning, and the need for an FRGF for SSRMS handoff to SRMS
  - Design must not preclude use of boom system for future EVA access for tile repair for Orbiter standalone and ISS missions after 1J
  - Boom system must not interfere with existing Orbiter structure
  - Boom system must minimize intrusions into the payload bay and dynamic envelope, and it must fit into the starboard sill SRMS envelope

Chronology of How Things Happened

- **Preliminary Design Reviews :** While the OBSS Project did not have a Preliminary or Critical Design Review (PDR/CDR), all the hardware providers did hold such reviews or held an equivalent Technical Interchange Meeting (TIM) that functioned as a PDR
  - **Boeing – MPMs:** Boeing design review TIM in November 2003
    - Key issues
      - Wiring was inadequate to support a high quality video signal
      - Wiring was not big enough to support the power requirements of the sensors
      - Structural loads were significantly exceeded
    - Because of the seriousness of these issues, Boeing held a formal PDR/CDR in late January 2004
  - **MDA – IBA:** Boom TIM in Mid-December 2003
    - Key Issues were similar to those identified at the Boeing TIM
      - Power, wiring, and fusing for the two sensors
      - Structural loads
      - Hardware clearances
      - Thermal effects
      - MPM rigging (the boom needed very tight tolerances to maintain straightness)

Chronology of How Things Happened

- **ASD/SNL – SP-1/LDRI:** TIM was held in December 2003
  - Projected launch date had now slipped to September 2004
    - Many changes were being made to the LDRI to make it more robust
      - Meet the functional criticality 1 requirement
      - Make it explicitly compliant with the detection and measurement requirement of 0.25 inches on WLE RCC
- **ASD/SNL**: PDR for the LDRI box on February 10 - 11, 2004
  - There were no major issues
- **Avionics System Division / Neptec – SP-2/LCS**: TIM December 2003
  - Key Issues
    - Thermal design
    - Electrical, Electronic, and Electromechanical (EEE) parts. The
      - EEE parts used by Neptec relied heavily on commercial ground parts and not on space-qualified parts.
        - Extensive radiation testing would be needed to ensure reliable operation in the space environment.
    - Building and certifying a what had essentially become a new criticality 1 box – it was no longer a DTO unit
    - Overall, delivery schedule

Chronology of How Things Happened

- **Avionics System Division /Neptec PDR:** May 11 – 13, 2004
  - LCS had undergone significant changes in design since December 2003
    - Materials changes
    - EEE parts changes, and
    - board layout
    - Change from 28 Vdc power operations to 124 Vdc
      - Keep alive heater power when the boom was berthed in the MPMs at 28 Vdc

- **Critical Design Reviews (CDR):** A few short months later, the Critical Design Reviews of the various elements of the OBSS began. One criterion for CDR is that 90% of the drawings be completed and released.
  - **Boeing – MPMs:** Delta CDR on April 29 – 30, 2004
    - Key issue: Structural Loads and certification testing
  - **MDA – Integrated Boom Assembly (IBA):** March 9 – 10, 2004 (28 Vdc single sensor option)
    - Key Issues
      - Due to power constraints, there was no good technical solution yet for powering the LCS
      - Structural loads and Power/wiring for the sensors.
      - Clearances between the boom and some EVA hardware
    - Proceed with a single sensor boom (supporting SP-1) for first flight
      - Support two sensors on the second boom studies for the second flight

Chronology of How Things Happened

- **ASD/SNL – SP-1/LDRI:** June 7 – 9, 2004
  - Key Issues
    - Definition of the content of the software releases for video image processing
    - Laser glass windows meeting the EVA tool impact requirements

- **ASD/Neptec – SP-2/LCS:** August 10 – 12, 2004
  - **Key Issues**
    - Thermal design.
      - Current design could not meet the hot 25 degree C environment.
        - Design change on the LCS and lowering the thermal environment to 5 degree C were required for the LCS to be able to safely operate.
    - Radiation testing failure for the EEE parts
    - Delivery Schedule

- **Modal Testing at Marshall Space Flight Center**: January 2004 – August 2004
  - Preparation began in January, with the testing taking place in July and August
  - The data was very good and correlated with the analyses quite well.

Chronology of How Things Happened

- **System Design Review (SDR):** August 31 – September 1, 2004
  - Every aspect of the OBSS was open to question to see if the system was ready for the next stage – Design, safety, operations, integrated testing, installation on the vehicles, and certification
  - Key Issues
    - SSRMS deployment and berthing timelines that exceeded the unpowered capability of the sensors.
    - The boom was still a one sensor boom although it was looking more and more likely that the LCS would be ready for STS-114.
    - The loads were still unresolved.
    - There were hardware clearance issues.
    - Schedules were still extremely tight
- **Integrated Vehicle Testing at KSC:** February 2005 and April 2005
  - Boom, LDRI and LCS tested with Orbiter Systems
- **Certification:** Completed July 9, 2005
  - A tiered approach was used to certify the OBSS.
  - The requirements in the SRD were allocated via the certification matrix, to the various hardware elements providers or to the integrated level

Chronology of How Things Happened

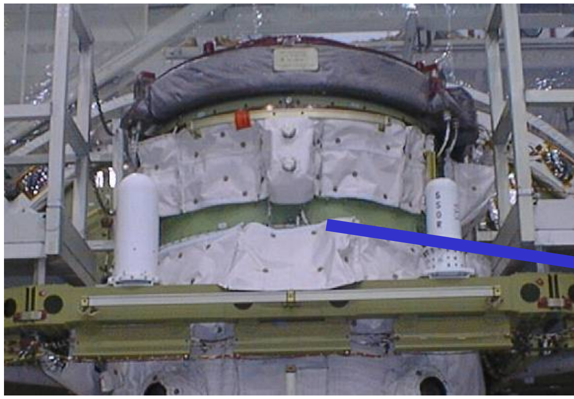
- **Flight Readiness Reviews:** April and June 2005
- The purpose of the FRR is to determine if the Orbiter is ready to fly
- For a May12, 2005 launch date, the FRR process occurred in early April 2005
    - Within days of completing the OPO FRR, the NASA Administrator announced that the flight would be slipped to NET July 13, 2005
        - Final FRRs commenced in mid-June

- **Certification**
    - OBSS final certification paperwork was signed on July 9, 2005

Technical Challenges

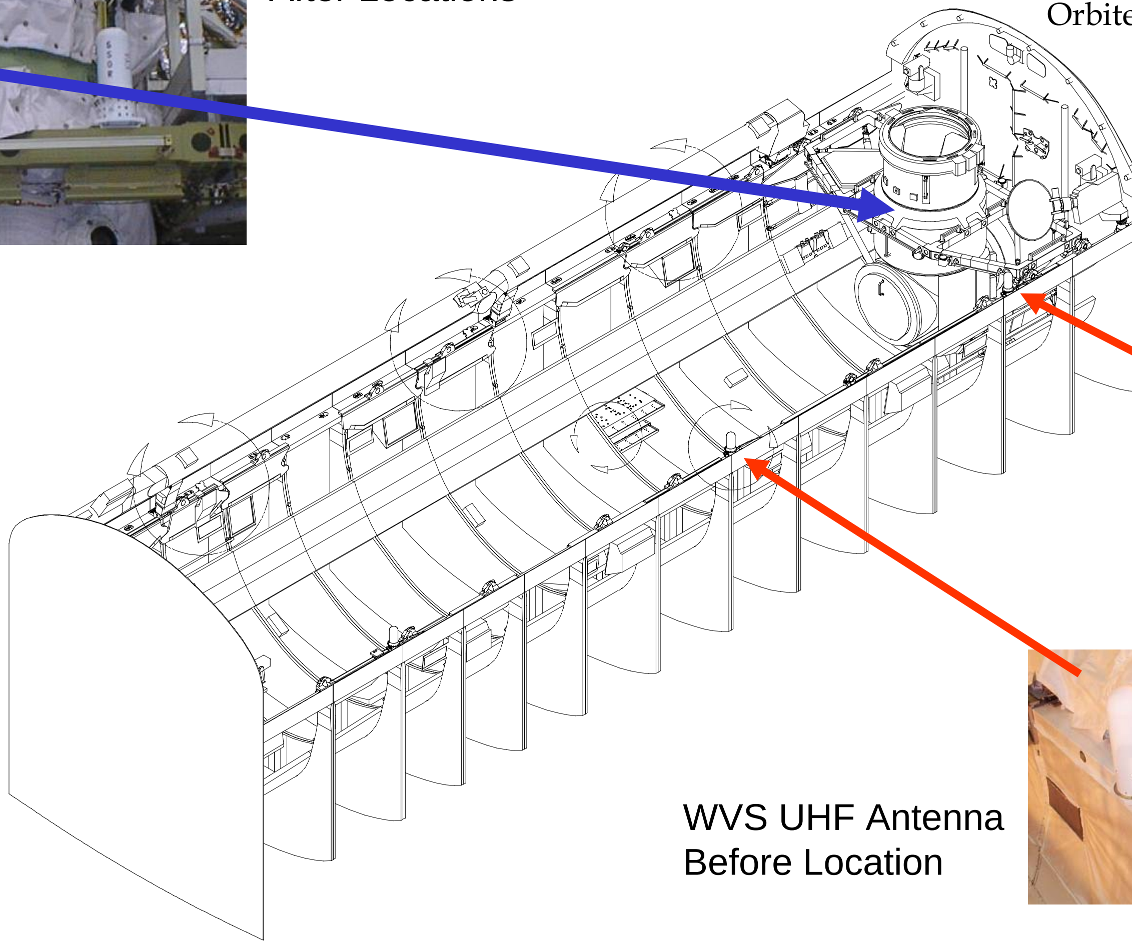
- Relocation of the WVS and SSCS UHF Antennas
- Orbiter Vehicle Wiring and Use of Existing Infrastructure
  - Video signal quality and sensor power
- New Software for Data Downlink
- Power Allocation and Distribution
  - Keep Alive heaters vs. operational power
  - Hybrid solution: LDRI at 28 Vdc and LCS at 124 Vdc operational
- 1 VS. 2 Sensor Debate
  - Schedule and sensor redesigns
- ➢ Vehicle Structural Loads
  - Boom structurally stiffer than the Orbiter
- Hardware Clearances
  - Sensors and boom with Orbiter structure and payloads
- ➢ Changing RCC Damage Criteria
- ISS Interfaces – the Use of the SSRMS
- Probability of Detection

Before & After Location of SSCS and WVS UHF Antennas

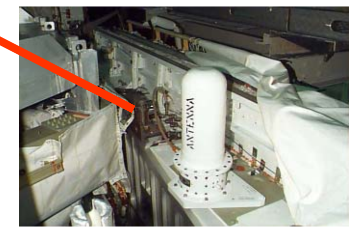


SSCS & WVS
UHF Antenna
After Locations

Orbiter crew cabin not shown



SSCS UHF
Antenna Before
Location

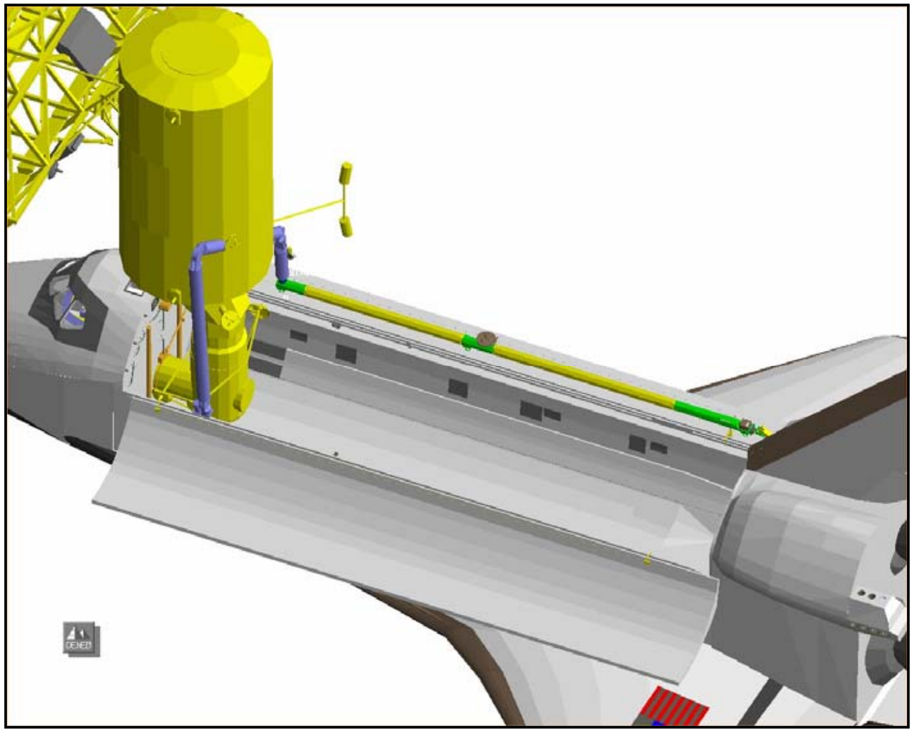


WVS UHF Antenna
Before Location

Clearance Issues

KU band antenna clearance with boom

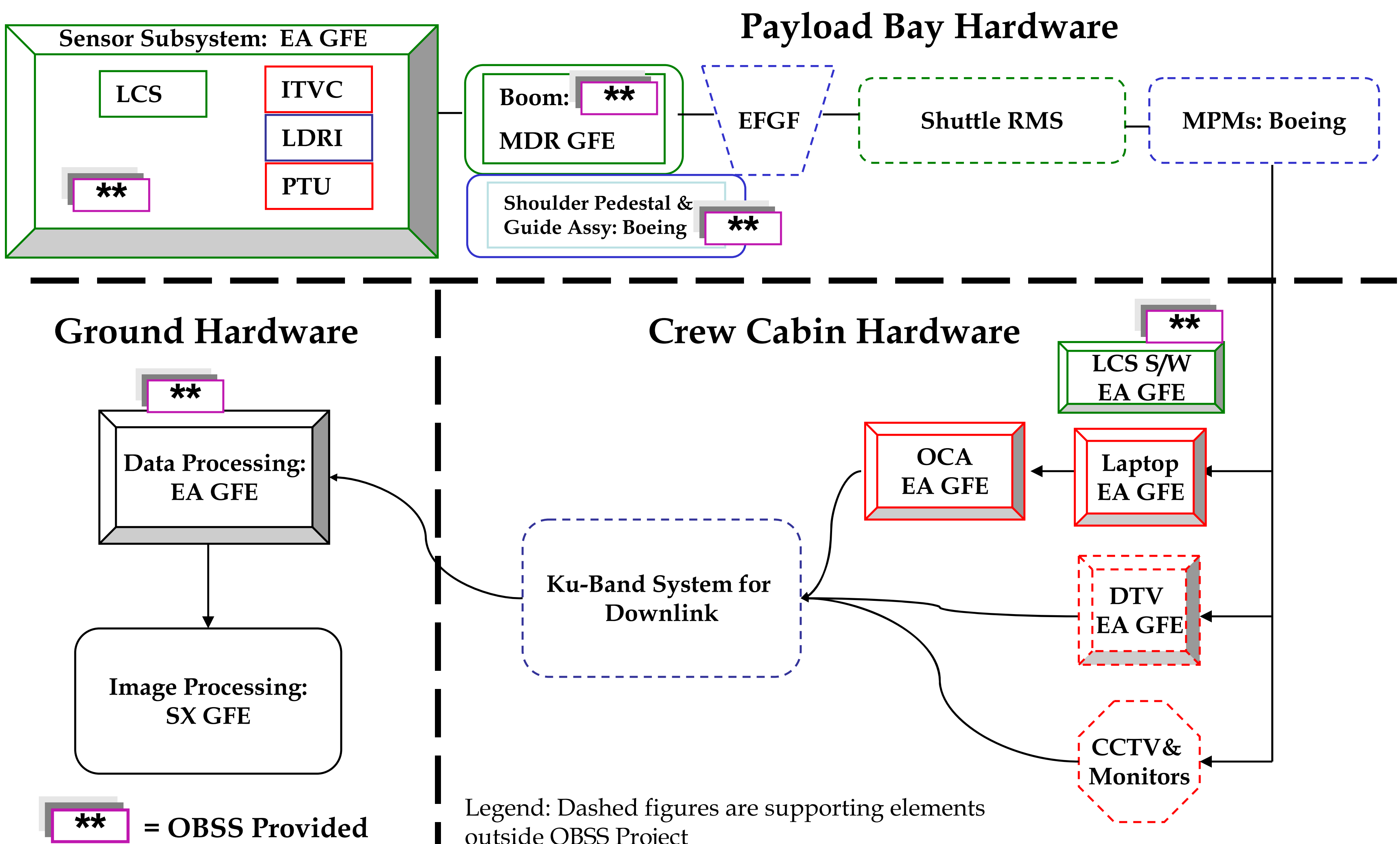
SRMS Cannot be used to grapple boom at ISS



Project Management Challenges

- Schedule Slips and How They Affected Decisions
  - Decisions had to be made that minimized schedule impacts and took the least amount of time to implement. Decisions were optimized for best technical solution given the available budget and time.
  - Hindsight is 20/20 principle
- How to Integrate Myriad Organizations and Hardware
  - One of the biggest challenges the Project faced was how to integrate the myriad organizations from coast to coast and internationally. Several solutions were incorporated.
    - Weekly Integration Meeting
    - Many side meetings, TIMs, and teleconferences
    - Having requirements
    - Definition of major interfaces
    - Single integrated project schedule
    - Single integrated end-to-end electrical schematic
- Criticality 1 vs. Criticality 3
  - The OBSS depended very heavily on existing infrastructure. While OBSS had been designated as criticality 1, much of this infrastructure was not. In general, a criticality 1 system has the same criticality of components throughout. OBSS did not.

OBSS Component Diagram



Legend: Dashed figures are supporting elements outside OBSS Project

Designed As: RED - Crit 3; Blue - Crit 2; Green - Crit 1

Project Management Challenges

- EVA Project Office
  - New, not baselined, requirements
- ISS Program Office
  - Responsible for the SSRMS
- Management Personnel Experience Level
  - New OPO management
  - New major hardware development for RTF
- EA Contract Change and Personnel Loss
- Late Change in Detection Requirements
  - The inspection or damage criteria for the RCC were not really firmly established until June 2005

Conclusion

- Overall, the OBSS Project went extremely well. All the individuals involved were extremely dedicated to the Return to Flight activity and recognized that this project was key to the success of the Agency. It was an amazing project. What would normally have taken 3 to 4 years to complete was successfully completed in less than 2, starting from the SRR in October 2003 to the flight of STS-114 in July 2005. All normal project processes were followed and no shortcuts were needed for success. The nearly flawless operations on STS-114 proved that all the hard work and long hours were justified. All team members associated with this project should be proud of their success. It was a great achievement.